

# AN INCIPIENT HURRICANE NEAR THE WEST AFRICAN COAST

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## ABSTRACT

The early history of hurricane Debbie of 1961 is presented, showing that it arose from a cyclonic disturbance which can be traced back into central Africa. The disturbance became well organized while still over land, and apparently possessed some features of the incipient hurricane before leaving the African coast.

## 1. INTRODUCTION

Evidence that some Atlantic hurricanes arise from disturbances which can be traced back into Africa has been mentioned by Piersig [1], Dunn [2], and Schove [3], among others. H. Hubert [4] tracked the New England hurricane of 1938 back in time to an origin in the south central Sahara. More recently, Riehl [5] has stated that many Atlantic waves can be traced back to the African coast or beyond; and Dunn and Miller [6] note that in at least one or two cases the circulations from which hurricanes later developed may have been observed in tropical Africa.

The 1961 season saw more than one such storm, and Debbie grew to hurricane strength farther east than did any of the others of that year—in fact, while still in the vicinity of the Cape Verde Islands. Dunn and staff [7] state that Debbie “probably developed between the Cape Verde Islands and Africa.” Thus the continuity in space and time between the developing hurricane and the westward-moving African disturbance out of which it grew is both shorter and more nearly certain than is the case with other storms of that year which may also have had such an origin.<sup>1</sup>

The remarkable feature of the westward-moving depression that gave birth to Debbie was that it appeared to have been in the formative stages of a hurricane even before clearing the African coast! Certainly the depression was deepening at that time, and it was already a well-organized disturbance while traversing the interior of West Africa.<sup>2</sup>

This report on the early stages of Debbie is a by-product

<sup>1</sup> Fritz [8] has evidence that hurricane Anna may have had such a history. There also is good evidence for believing that Esther developed from an easterly wave moving out of Africa.

<sup>2</sup> Mr. Earl S. Merritt of Allied Research Associates, Concord, Mass., has been concurrently investigating the early stages of Debbie and other disturbances of African origin which arose during September 1961. Some of his work was recently reported in a paper given on December 29, 1962 at the Second Western National Meeting of the American Geophysical Union, Stanford, Calif.

of a larger and more general investigation into the history of incipient storms, using both satellite and conventional data. Only conventional data were available for the early stages of this disturbance; satellite pictures were not obtained until after it had moved out over the Atlantic. However, the network of surface and pibal stations over West Africa is moderately dense and permits a reasonably accurate synoptic analysis at lower levels, with good day-to-day continuity during the formative stages of this storm. The later history, during which both satellite and conventional observations contributed to storm detection and tracking, has been given by Dunn and staff [7].

## 2. SYNOPTIC SITUATION AND CHRONOLOGY

During much of August and September 1961, a somewhat irregular series of low-level perturbations traveled westward across West Africa and into the Atlantic. These perturbations in the wind field were mostly centered between latitudes 10° and 15° N., were strongest near the 700-mb. level, and their presence and movement generally were indicated by accompanying areas of sea level pressure rise and fall and accompanying areas of disturbed weather. The wave spacing was roughly 20° of longitude, and the speed about 5° to 7° of longitude per day, so that the westward progression past individual stations was at the rate of one wave every three or four days. Superficially at least, these waves seem to be much like the westward-moving perturbations of the Caribbean and Pacific areas previously described by Riehl [5], Palmer [9], and others.

Figure 1 shows the 700-mb. analyses for the first six days of September 1961 over a portion of West Africa and the nearby Atlantic. The waves were somewhat better developed during this 6-day period than they were at some other times during August and September, but a similar pattern prevailed over most of the longer period, and the evidence indicates that such a pattern probably is an

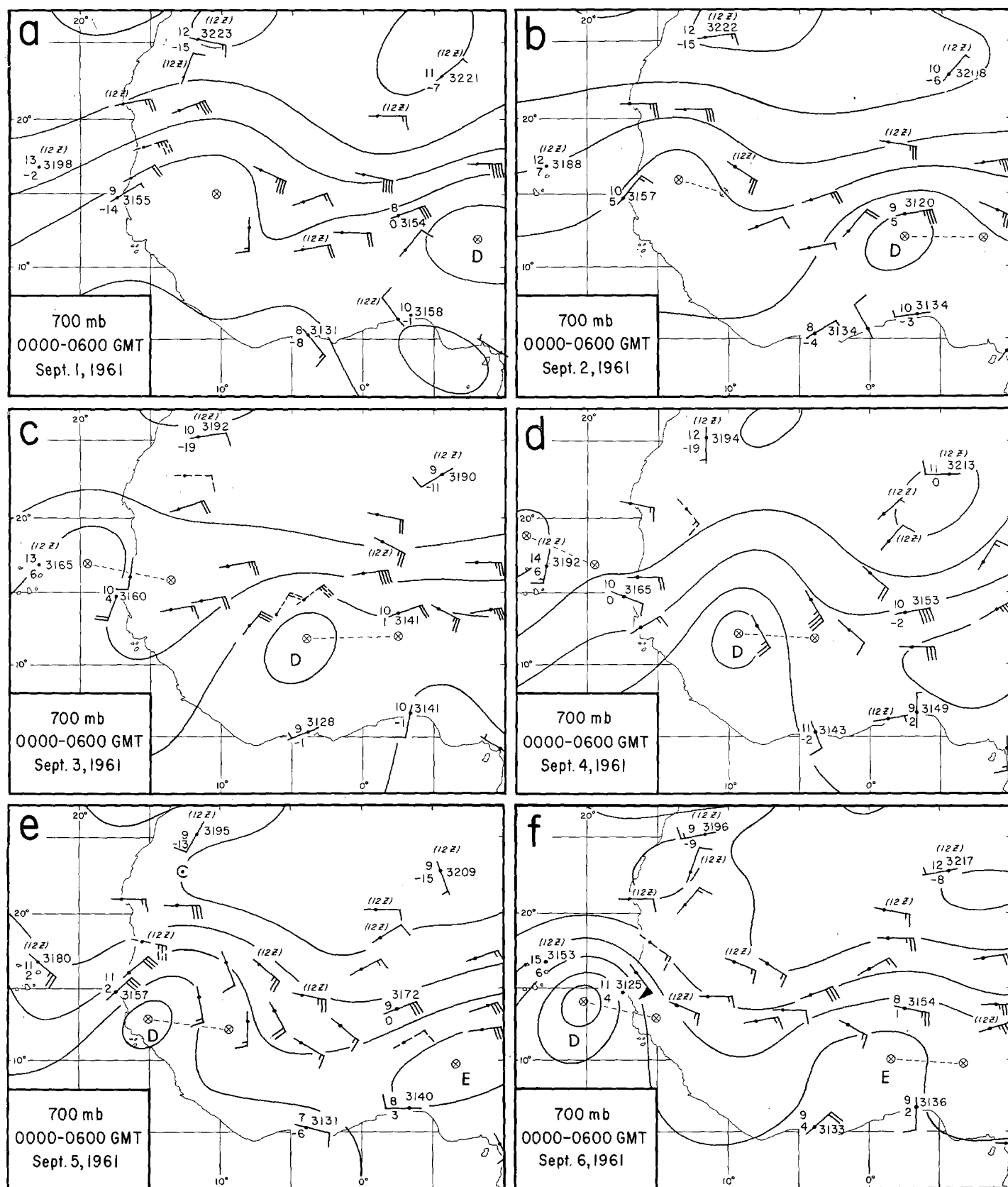


FIGURE 1.—700-mb. data and contours for September 1-6, 1961. Contour interval 20 gpm. The symbols  $\otimes$  mark the current and 24-hr. past positions of disturbance centers. D and E indicate troughs from which Debbie and Esther developed.

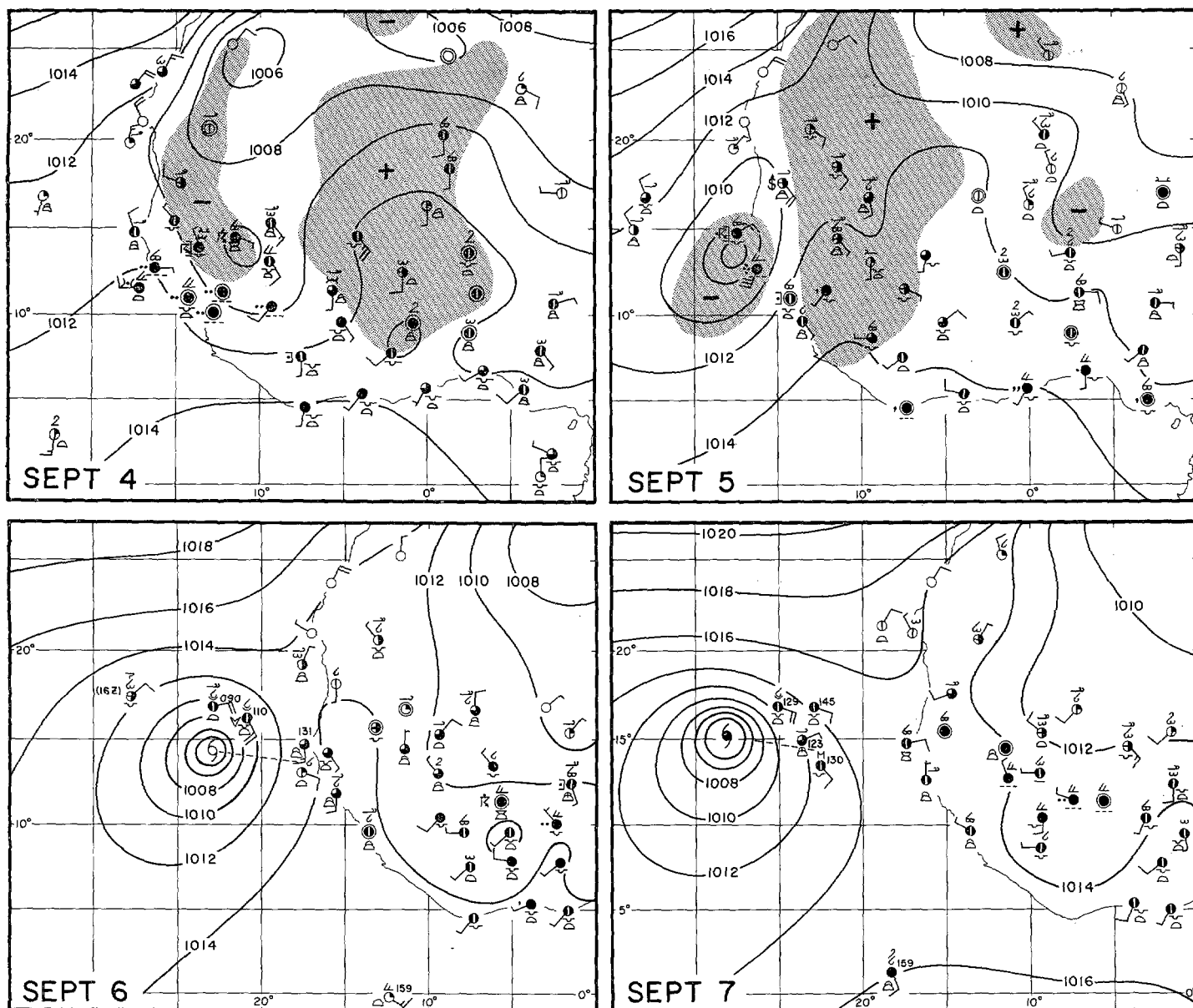


FIGURE 2.—(a) Surface charts for 1200 GMT September 4 and 5, 1961. Shaded areas are regions of 24-hr. pressure change greater than 2.0 mb. The number of stations shown is about half the number within the same area actually used in the analysis. (b) Surface charts for 1200 GMT September 6 and 7, 1961. Dashed line is estimated track of storm from its position on previous map.

annual summer feature (see Piersig [1] and Schove[3]). Contours are drawn in figure 1, rather than streamlines, partly to show that the winds seem to be not far from the geostrophic direction even at these low latitudes. Deviations are mostly with speeds, which tend to be subgeostrophic.

The troughs labeled D and E, in figure 1, are the ones from which hurricanes Debbie and Esther later developed. Esther will not be discussed here, except to state that there was continuity between the African trough and the subsequent Atlantic hurricane. The disturbance D, from which Debbie later developed, is seen over Nigeria, near the eastern edge of the map, on September 1, and there is

evidence for its prior existence, even farther to the east, over central Africa. As the wave moved westward at about 6° of longitude per day, the amplitude gradually increased, and the trough had become noticeably better defined as it approached the coast on September 5. The surface depression accompanying the 700-mb. trough likewise became more evident as it progressed westward, deepening slowly, at the rate of about 1 mb. a day, from September 1 through September 4.

A more pronounced intensification of the surface Low occurred between September 4 and 5. Figures 2a and 3 show the surface analyses and some of the plotted data for those two dates. The center of the depression appears

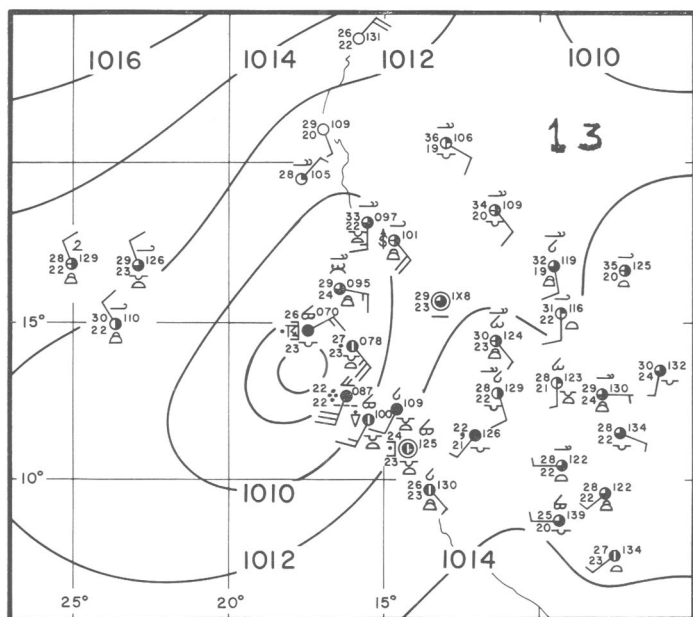


FIGURE 3.—Enlarged section of surface map for 1200 GMT, September 5, showing more complete data.

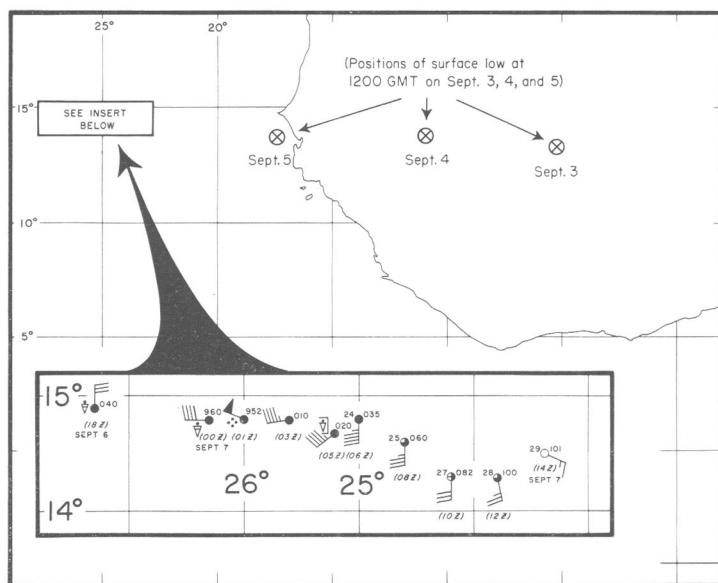


FIGURE 4.—Reports from the Danish ship *Charlotte Maersk*, on September 6 and 7, 1961.

on the coast just south of Dakar ( $15^{\circ}$  N.,  $17\frac{1}{2}^{\circ}$  W.) at 1200 GMT, September 5, and the increased circulation is obvious. (Note that the time (1200 GMT) of these surface maps is later than that of the 700-mb. charts, which are based largely on the combined data for the hours 0000–0600 GMT).

Early on September 6, disturbance D was out over the Atlantic, and its intensity can only be estimated (see fig.

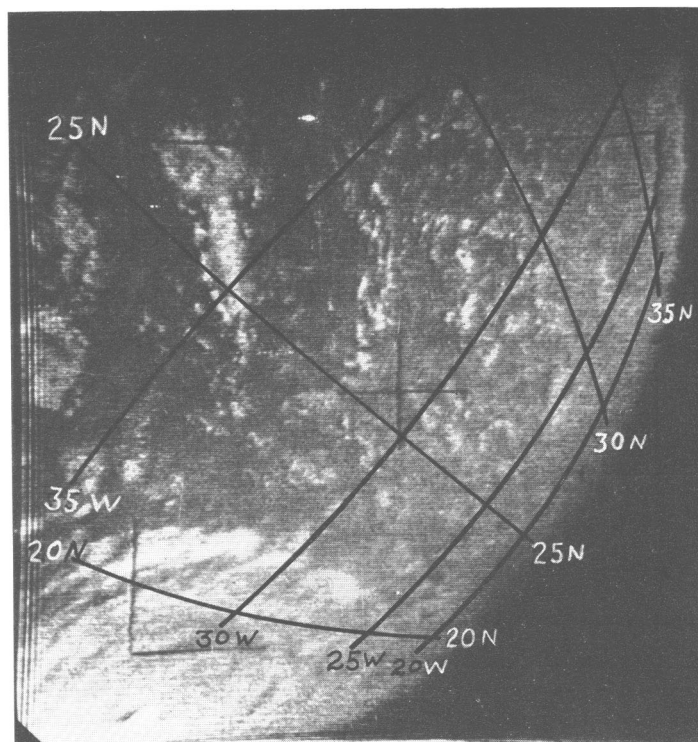


FIGURE 5.—TIROS III photograph of hurricane Debbie taken at 1913 GMT, September 7, 1961. The eye is visible in the lower left corner. Its location is estimated to be within  $1^{\circ}$  of latitude of  $15.5^{\circ}$  N.,  $29.5^{\circ}$  W.

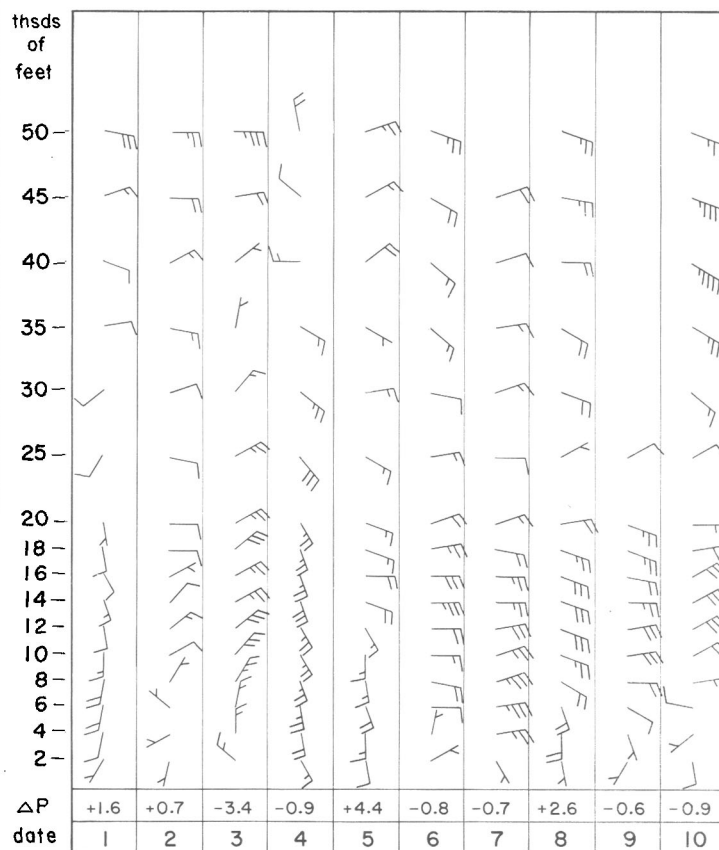


FIGURE 6.—Time cross-section for Bamako, Mali ( $13^{\circ}$  N.,  $8^{\circ}$  W.) September 1–10, 1961, 0600 GMT observations.  $\Delta P$  is the change in station pressure (mb.) for the 24 hours ending at 0600 GMT.

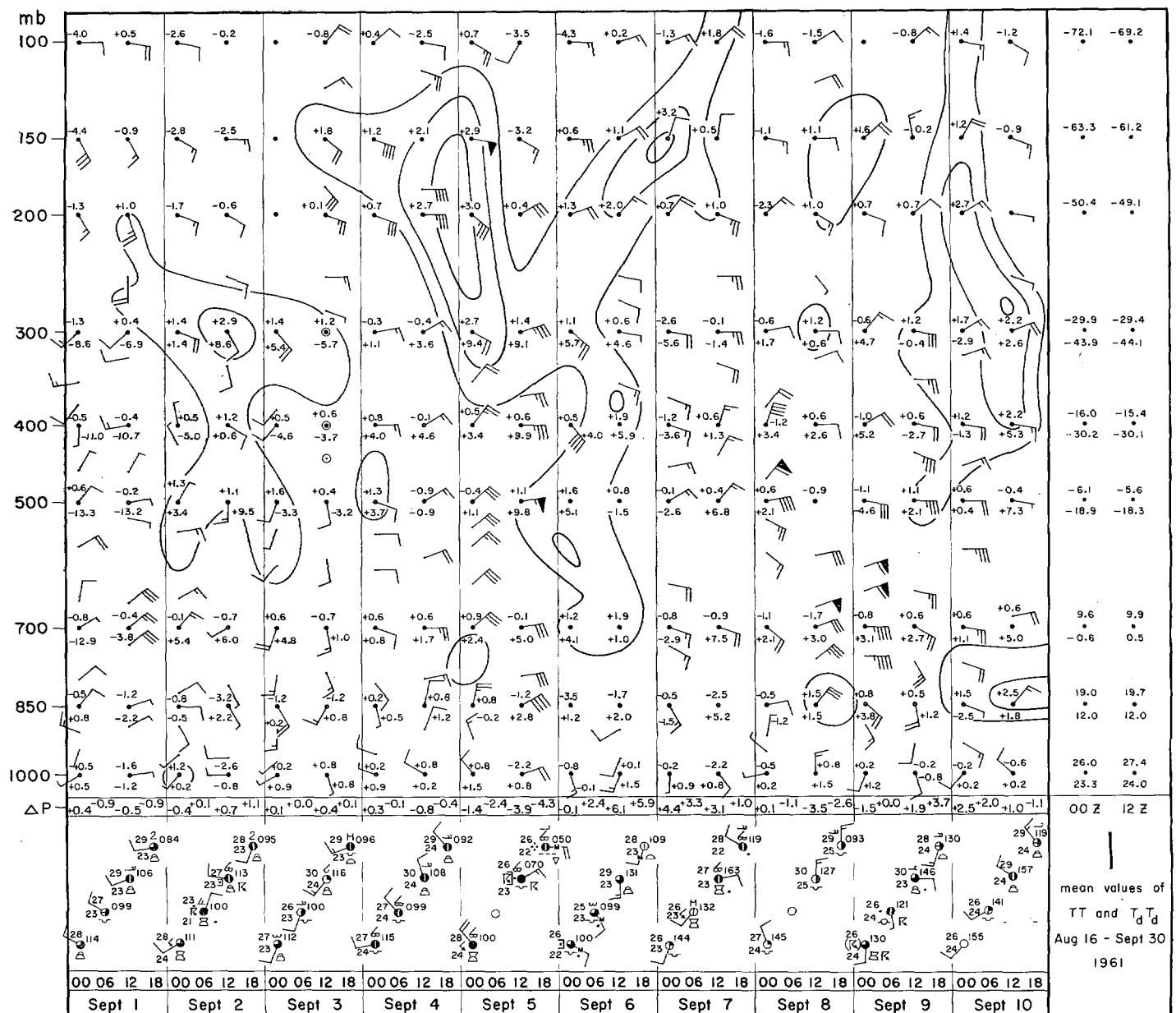


FIGURE 7.—Time cross-section for Dakar, Senegal (15° N., 17.5° W.) September 1-10, 1961. Plotted numbers above and below observation points are the deviations of temperature and dew point, respectively, from the means of the period August 16-September 30, 1961. Mean values are at right. Areas of warming greater than 1° C. above the mean are enclosed by isolines.  $\Delta P$  is 24-hr. station pressure tendency.

1f), but the 52-kt. SE wind above the coastal station of St. Louis (16° N., 16½° W.) signifies that further growth probably had occurred. Rawinds over Dakar at this time are missing up to 400 mb., at which level the wind was SE 41 kt.

Late on September 6 and early on the 7th, according to Dunn and staff [7], several surface reports from the Danish tanker *Charlotte Maersk* indicated that a storm, probably already of hurricane intensity, existed near 15° N., 25° W. The plotted reports from that ship are shown in figure 4.

Shortly after 1900 GMT, September 7, at which time the

storm center was near 16° N., 29° W., the first satellite picture of Debbie was taken by TIROS III (see fig. 5). The picture shows slightly more than half the area of the hurricane, including the eye. Spiral bands extend to latitude 21° N., more than 300 mi. distant from the center.

On the basis of this evidence for the continuity and intensification of the storm after it left the African coast on September 5, the surface analyses for 1200 GMT, September 6 and 7 are presented in figure 2b. The available synoptic reports from peripheral areas of the storm on those two days strongly suggest the presence of a cyclonic disturbance, but do not by themselves indicate the inten-

sity of the cyclone or the precise location of the center. The special ship observations of figure 4 provide proof of intensification to near-hurricane force, and the gridded TIROS photograph of figure 5 locates the eye at a later time more accurately than might otherwise have been the case. Consideration of these items enables one to extend the surface analyses to the storm area with a greater degree of confidence.

### 3. SOME INFERENCES ABOUT THE VERTICAL STRUCTURE

Figures 6 and 7 show time cross-sections of upper winds for Bamako, in the interior of West Africa ( $13^{\circ}$  N.,  $8^{\circ}$  W.), and of rawinsonde data for Dakar, on the coast ( $15^{\circ}$  N.,  $17\frac{1}{2}^{\circ}$  W.), for the first ten days of September. A pronounced cyclonic wind shift to 35,000 ft. occurred at Bamako between September 3 and 4 as the depression passed. A similar wind shift to above 400 mb. undoubtedly occurred at Dakar two days later, but confirmation of this is not certain because of missing winds in the lower levels on September 6. Such a cyclonic wind shift through a deep layer of the lower troposphere is of greater vertical extent than that usually associated with easterly waves.

Upper air temperatures and dew points were not available from Bamako. For Dakar these data are plotted as deviations from the mean of the 46-day period, August 16 through September 30, 1961, it being thought that the mean values at standard levels for this longer period constitute a more significant and reliable base than either the means for the shorter 10-day period of the cross-section or the mean tropical atmospheres. (The latter are based on Caribbean data and are colder than the Dakar 46-day mean at nearly all levels.) Separate means were computed for 0000 GMT and 1200 GMT Dakar data. Rawinsonde ascents for 0000 GMT were made on every day of the 46-day period, and reached at least to the 150-mb. level on all but two of those days.

The 1200 GMT Dakar data probably are less reliable than those for 0000 GMT for three reasons: (a) possible instrumental error due to solar exposure (the 1200 GMT mean is warmer than the 0000 GMT mean at all levels), (b) the teletypewriter source of the 1200 GMT data, (c) the fact that 7 of the 46 soundings were missing from the teletypewriter source, possibly causing the computed mean values for 1200 GMT to be slightly in error. However, it is felt that the 1200 GMT data, though less reliable than those for 0000 GMT, should not be ignored.

The temperature structure at Dakar was remarkably stable in time during this period, as might be expected from such a low-latitude station. However, one can note the large area of above-average temperatures on September 4-6 when the depression was in the vicinity, with the greatest warming occurring in the upper troposphere on 0000 GMT, September 5, as the depression was approaching and was very near the station. The thickness of the air column, 1000 mb. to 150 mb., at that time was in fact exceeded on only one other day of the 46-day period. The

warming at upper levels between 300 mb. and 150 mb. at 0000 GMT, September 5, largely accounted for the increased thickness of the entire column.

At 1200 GMT, September 5, at which time the depression was passing just south of Dakar, a relative cooling was observed, especially at very low and very high levels. From this, one might be tempted to conclude that the disturbance was still essentially of a slight cold-core nature, surrounded by warmer air. Such a conclusion is questionable, because of the thunderstorms in the vicinity of the radiosonde at that time plus the greater errors inherent in daytime soundings generally.

The deviations from mean dew point values are larger and more irregular than the deviations of temperature. Because of the greater inaccuracies involved in humidity measurements, the fluctuations probably are less significant than those of temperature. However, the relatively high dew point at 300 mb. at 0000 GMT, September 5, probably reflects the ascent of moisture from lower levels, indicating that the warming also noted at 300 mb. was not due to compression in subsiding air. Horizontal advection alone seems unlikely to account for the warming owing to the fact that the 300-mb. temperature over Dakar on September 5 was higher than that for any of the other 19 North African and nearby island radiosonde stations, both for that day and for the previous day (excepting only the September 4, 1200 GMT report for Tamarrasset, in the Sahara). Therefore the most likely explanation of the 300-mb. warming over Dakar on the 0000 GMT, September 5 sounding, seems to be that it was largely due to the addition of latent heat in the approaching disturbance, and any advection that occurred was from this nearby source rather than from more distant areas.

It is, of course, not known to what extent or to what height the addition of latent heat in ascending air might have taken place. Moisture was not reported above the 300-mb. level, whereas the warming (relative to undisturbed air at the same level) over Dakar occurred at all levels from 400 mb. to 70 mb. One can speculate that a level of maximum horizontal divergence probably existed at some upper-tropospheric level, say 200 mb. Below that level moist air was ascending, warmed by the release of latent heat. Immediately above that level dry air was descending, warmed by compression. The relatively strong winds at 200 mb. and 150 mb. over Dakar at 0000 GMT on September 5, are directed away from the approaching disturbance at a speed greater than the speed of the disturbance itself, and thus represent air which has been ejected from nearer the center. This could explain why the greater warming at those levels was observed on September 5, as the disturbance was approaching, rather than on September 6, after it had passed.

Figure 8 shows the plotted 200-mb. data and streamlines for September 2, 3, 4, and 5. Owing to the relatively sparse data and the nonuniform times of the observations, the streamlines that are presented are only

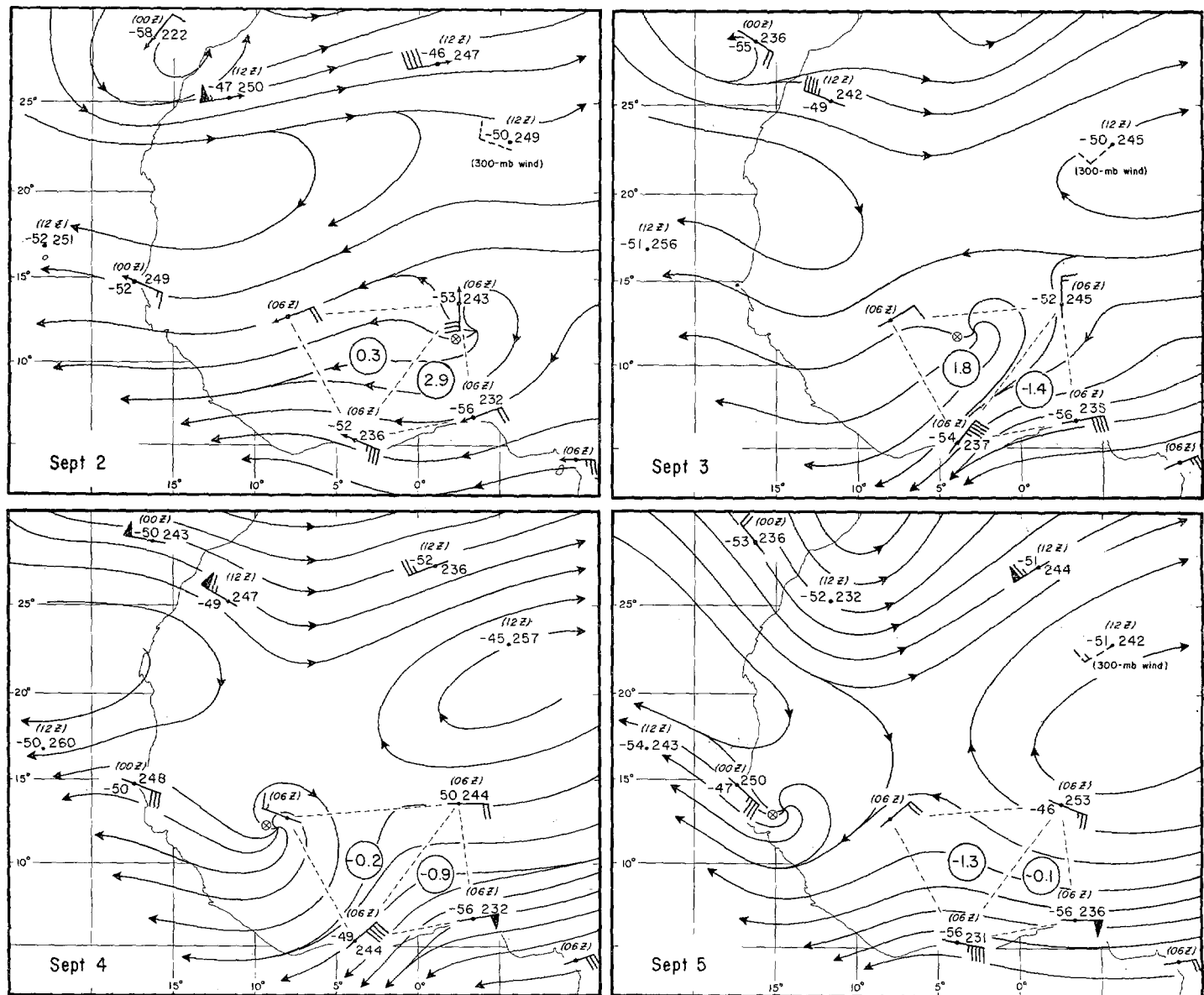


FIGURE 8.—200-mb. data and estimated streamlines for September 2, 3, 4, and 5, 1961. Heights are in tens of geopotential meters, with first digit omitted. Circled numbers are computed values of divergence for the triangular areas (dashed lines) in units of  $10^{-5} \text{ sec.}^{-1}$ . The symbol  $\otimes$  denotes the approximate 700-mb. center of the disturbance at 0600 GMT.

an estimate of actual synoptic conditions. They are shown to depict two main features: (1) a large-scale east-west ridge of high pressure, oscillating about latitude  $20^\circ \text{ N.}$ , with general westerly flow north of that latitude and general easterly flow south of it; (2) to the south of the main ridge, an apparent anticyclonic eddy which accompanied the incipient storm as it moved westward.

Evidence for the existence of the traveling anticyclonic eddy is based largely on the winds at Niamey ( $13\frac{1}{2}^\circ \text{ N.}$ ,  $2^\circ \text{ E.}$ ) on September 2 and 3, and at Bamako ( $13^\circ \text{ N.}$ ,  $8^\circ \text{ W.}$ ) on September 4. At first glance these particular winds might appear to be questionable, but winds at adjacent levels above and below 200 mb. tend to support the idea that they are real. The wind observations were

obtained from code sheets copied from original records.

Also shown in figure 8 are computations of horizontal divergence for two triangular areas between reporting stations, following the method described by Bellamy [10]. That method uses only the actual winds at the corners of the triangle and assumes a linear variation of the wind between stations. Because of this and because of the large and irregular triangular areas resulting from the sparse data coverage, the computations of divergence yield only rough estimates. However, for those computations that are not near zero, the sign, at least, is probably correct; and it is interesting to note the relatively large positive values that occur on September 2 and 3 in the triangular area above the 700-mb. disturbance.

On September 4 the disturbance was west of Bamako and beyond the area suitable for computation, but the large directional divergence between the 200-mb. winds at Bamako and Dakar indicates that, in all likelihood, considerable actual divergence continued to exist at that level over the incipient storm.

#### 4. SUMMARY AND CONCLUSION

(1) Hurricane Debbie developed from a cyclonic disturbance which can be traced back into central Africa.

(2) The disturbance moved westward across West Africa at about 6° of longitude a day. Both the 700-mb. wave and the accompanying surface depression became slowly but progressively more pronounced during the 3-day period immediately preceding their arrival at the coast on September 5. Rainfall increased. There is evidence that organized divergence at 200 mb. accompanied the disturbance during this time.

(3) The surface depression was deepening as it crossed the coast on September 5, and winds increased to hurricane force within 48 hours. Although knowledge of hurricane formation is incomplete, the available evidence suggests that at least some of the necessary ingredients of the incipient hurricane were in existence immediately prior to the arrival of the depression on the coast. Possibly the only missing factor was the moisture source of the tropical ocean.

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